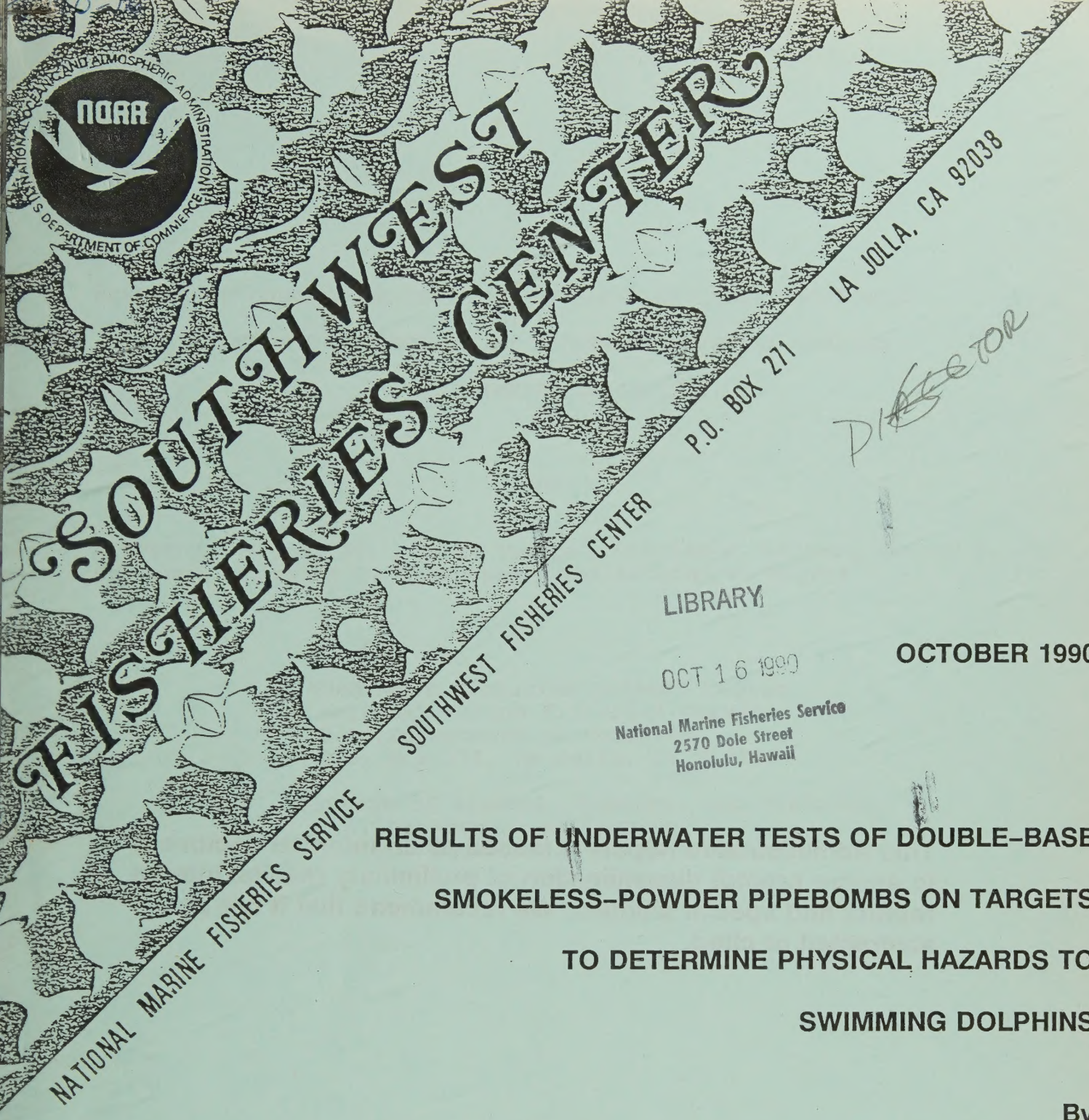


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# RESULTS OF UNDERWATER TESTS OF DOUBLE-BASE SMOKELESS-POWDER PIPEBOMBS ON TARGETS TO DETERMINE PHYSICAL HAZARDS TO SWIMMING DOLPHINS

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ADMINISTRATIVE REPORT LJ-90-26

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By

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# Results of underwater tests of double-base smokeless-powder pipebombs on targets to determine physical hazards to swimming dolphins

By

Albert C. Myrick, Jr., Jerry Taylor, Charles W. Oliver, Edward R. Cassano, Lawrence L. Robertson, and Anthony P. Majors

## ABSTRACT

We exploded four PVC pipebombs containing 130, 130, 293, and 366 grains (8.42, 8.42, 18.99, and 23.72 grams) of double-base smokeless powder underwater on dolphin carcasses and cages of live fish to detect mechanical blast damage and to determine impulse pressures that would allow us to estimate injury or mortality to live swimming dolphins. The two strongest charges produced impulse pressures of 21 and 35-40 psi-msec respectively at 0.5 m from the point of explosion and could have caused serious injuries to live dolphins at that distance. Such devices could cause very serious injury, perhaps death, to dolphins at or very near ground zero.

## INTRODUCTION

Between 3 and 5 September 1989, a fisherman set off a number of homemade pipebombs, suspended from a fishing line, underwater, near dolphins in order to drive them away from his fishing gear. It is clear from his statements that he exploded the devices knowing that they could cause serious injury to the dolphins. According to analyses of six similar devices, confiscated from the fisherman by authorities, the bombs were made from polyvinyl chloride (PVC) pipes 0.75 to 1.0 inches (1.91 to 2.54 cm) in diameter, ranging in lengths of 3 to 6 inches (7.62 to 15.24 cm), and containing from 95 to 366 grains (6.16 to 23.60 grams or 0.0126 to 0.0484 pounds) of double-base smokeless powder. For a detonator, an automobile taillight with bulb broken to expose the filament to the powder was sealed inside each pipe with connecting wires leading to a 12-volt battery power-source. Closing the cicuit between power-source and taillight would cause the filament to incandesce, thereby igniting the powder and initiating the explosion reaction.

### Purpose of the Study

Testimony in the case was unable to establish whether injury or mortality was actually sustained by the dolphins. Although the dolphins were not present after the several devices were detonated near them, no sightings of dead or injured dolphins were reported in the area during the period. We were asked to research the question of whether devices of the construction used by the fisherman could cause serious injury or mortality to dolphins

swimming nearby. Here we account the background, procedures, and results of the investigation.

## Nature of Damage by Underwater Explosions

Underwater explosions produce characteristic blast and compression waves. Small smokeless powder pipebombs, as with most other small explosives, would be expected to produce some blast injury, even mortality, from short-range displacement of water, propelled shrapnel, and heat from rapidly expanding high-temperature gases. However, because water is highly resistant to the displacement effects of blast, the effects would wane quickly and generally would be harmful only very near the explosion point.

In most experiments with small explosives, the model used to predict damage is that of a spherical charge which projects explosive energy rather uniformly outward in all directions. Pipebombs are cylindrical, with inherent weaknesses at the capped ends. An underwater explosion of a pipebomb would tend to blow off the weaker of the two ends, propelling the cylinder and the cap through the water for a short distance at bullet-like speeds. Any organism near the point of the explosion and in the path of the "bullet" would be expected to sustain a direct injury or mortality.

While an underwater blast causes displacement of water that moves outward from the source a short distance as a physical outflow of water, the explosion imparts to the water a compression wave that moves outward as a steep pressure front of maximum peak pressure (Pmax), followed by a rapidly decaying pressure tail. The total compression wave, from the pressure front to the end of the tail (i.e., the total amount of pressure that passes through a given point in the water) is known as the impulse pressure (I). Pmax is a measurement of peak pressure, while I is the integral of the total pressure over time. As would be expected, Pmax and I dampen out fairly rapidly with distance as the energy of the explosion is absorbed by an increasingly greater water volume (Cole 1948; Beeb 1951; Christian and Gaspin 1974, Myrick et al. 1990a).

## Injury and Lethality of the Compression Wave

It is the consensus of underwater explosives experts that although Pmax is of considerable importance as a factor in estimating injury and mortality to submerged animals, it is the intensity of I that is of greatest importance. Experiments in the 1970's, in which the effects of small underwater explosions were tested on submerged live land mammals as large as adult sheep (40 kg), allowed the investigators to establish a consistent relationship between the strength of I and the degree of injury to a submerged mammal (Richmond et al. 1970; Yelverton et al. 1973; our Table 1). These criteria generally apply irrespective of the level of Pmax.

High Pmax's can kill or injure, but lower Pmax levels are capable of accomplishing similar damage when levels of I are high. According to Christian and Gaspin (1974) no injury has ever resulted at impulse pressures as low as 2.0 pounds per square inch per millisecond (psi-msec) even with Pmax as high as several hundred psi. However, I's above 5.5 psi-msec with Pmax's below 200 psi have resulted in injury to submerged mammals as large as 40 kg (Richmond et al. 1970; Yelverton et al. 1973). Safe standoff guidelines for U.S. Navy swimmers subjected to underwater explosions have been established at no more than 50 psi Pmax and 2.0 psi-msec I (Christian and Gaspin 1974). Navy guidelines for minimum risk of some injury to unprotected swimmers (in contrast with a "safe" range) is an I equal to or less than 10 psi-msec (Gaspin 1983).

Characteristics of Smokeless Powder

Smokeless powder is a class of common propellents used in small arms ammunition and it is usually given brief treatment in the explosives literature. Almost no reliable non-proprietary information is available regarding the shock wave pressures released by explosive devices made with smokeless powders either in air or water. Most existing information is anecdotal or in the form of statements which lack a discussion or presentation of experimental data.

Double-base smokeless powders consist principally of lightly nitrated granular nitrocellulose and nitroglycerine (Di Maio 1985). Although these components are commonly associated with high velocity explosives such as dynamites, in smokeless powders they have a propellent formulation that is intended not to produce a high explosive result, i.e., they are made to push a mass, not to explode it. Smokeless powders are considered to be similar to black powders in that they "deflagrate" (burn rapidly) when ignited without confinement, as compared with high explosives which "detonate" (explode at supersonic velocities, commonly between 3,000 and 5,000 m per second) (Di Maio 1985). Nevertheless, bomb experts in law enforcement agree that "...smokeless powder that is confined in ...a section of pipe...capped on each end and ignited by a length of fuse, will explode with great force " (Stoffel 1977, p. 55). At least one proprietary article among the "working literature" widely used by bomb and arson enforcement departments describes the explosion behavior of double-base smokeless powder in confinement as being "less than 23,000 f.p.s. [feet per second] or 7,000 m.p.s." (pers. comm. M. Fink, San Diego County Sheriff's Department Crime Lab, 1990). This velocity, even for confined materials, seems to us unreasonably high.

These and other sources do not describe how great the force or how much less than 7,000 m.p.s. the detonation velocity of a smokeless powder pipebomb may be. Although they gave some indication that the explosive power of such devices may have some

percent TNT (high velocity explosive) equivalency rating, no values were available to determine that equivalency. Thus, we could not use a modification of the standard TNT formulae to calculate Pmax or I for underwater explosions of pipebombs as was done by Myrick et al. (1990a) to estimate pressures for small chlorate explosives.

## METHODS AND MATERIALS

As an alternative to estimating potential dolphin injury by direct calculations of Pmax and I for the pipebomb explosions, we decided to estimate explosion pressures indirectly by detonating smokeless-powder devices underwater on targets suspended from a floating array at sea. For these experiments, we followed procedures described for open-water tests previously conducted to determine Pmax and I for small "M-80"-type explosives (Myrick et al. 1990b).

### Target Array

We used a 3.0 x 1.5-m rectangular frame of PVC pipe and cables made buoyant in the water by eight 0.78-m spherical floats. From this framework were suspended a vertical cable to which the explosive device was attached and three vertical cables to which targets were attached and whose distance from the explosive could be easily altered (Fig. 1).

### Swimmers

The array was serviced by three swimmers who attached explosives and targets, adjusted target distances, checked and changed targets, and gave immediate descriptions of items affected by each test to three data collectors in two boats. No swimmers remained in the water during explosion of devices.

### Devices

We tested four devices constructed and rigged for detonation according to the specifications of three devices confiscated from the fisherman. Two of these pipebombs were 3.0 x 0.75 inches (7.62 x 1.91 cm) and contained 130 grains (8.424 gm or 0.0173 lb) of powder, one was 6.0 x 0.75 inches (15.24 x 1.91 cm) and contained 293 grains (18.986 gm or 0.0389 lb) of powder, and one was 4.25 x 1.0 inches (10.8 x 2.54 cm) and contained 366 grains (23.60 gm or 0.0484 lb). Each was positioned on the vertical cable and ignited electronically using a 12-volt battery power-source in one of the boats. The array was allowed to drift at least 10 to 20 feet away from the boats before ignition of each device to ensure that the boats and occupants would not be affected.

Targets

Targets consisted of two dolphin carcasses and metal wire cages of live fish (mostly walleyed surfperch, Hyperprosopon argenteus). The carcasses were used to try to detect direct mechanical blast damage such as burns, cuts, bruises, ruptured tissues or bone fractures. They were examined externally immediately after each shot and examined carefully externally and internally the following day. Fish injured by the shots were saved, refrigerated overnight in 4°-C salt water, and weighed and necropsied the next day to quantify their size and to rate the extent of their injuries.

Fish Injury-Mortality Criteria

Explosion injury of fish was rated following the criteria first used by Hubbs et al. (1960) and widely accepted by others (e.g., Wiley et al. 1981; Baxter et al. 1982):

0 = No damage.

1 = Only light hemorrhaging, chiefly to tissues near the kidneys.

2 = Swimbladder intact, but with light hemorrhaging in body cavity and some kidney damage.

3 = No external indication of damage, but with ruptured swimbladder. Some hemorrhaging and obvious organ disruption, with gross damage to kidney.

4 = Incomplete break through body wall, but with anal blood. Swimbladder usually broken and organs damaged as in 5 (below).

5 = Rupture of body cavity evidenced by slit to the side of midventral line. Swimbladder burst and gross damage to other internal organs. Abdominal contents are often lost or homogenized.

In underwater explosion studies which included fish, birds, and mammals, Yelverton et al. (1975) counted fish as killed if they did not survive as long as two weeks after explosion exposure. Other studies of explosion effects on fish and their subsequent injury ratings by Wiley et al. (1981) led these investigators to conclude (p. 268) that "...injury level 3 or greater [correlates] with the observed fish-kill (dead and dying fish on surface and bottom) on [sic] underwater explosion tests, and injury level 2 or greater is considered to give the fish little chance to survive predation."

In our study, a fish was counted as injured if it displayed uncontrolled behavior, such as being disoriented, unusually ataxic, negatively buoyant, or unable to right itself. Because of severe time constraints during the tests, injured fish were sacrificed within a few minutes after each shot. This precluded our being able to fairly judge the specimens as severely injured or killed on the basis of post-explosion behavior. Following conclusions reached by Yelverton et al. (1975) and Wiley et al. (1981), discussed above, we counted fish as killed if they displayed injury behavior after the shot and if subsequent necropsy indicated an injury rating of 3 or greater.

Estimation of Impulse Pressures

In our study, the fish targets were used to try to estimate impulse pressures from percent killed or injured in each shot and the weights of the fish so affected. This was possible because of consistent relationships between measured impulse pressures and predictable percent weight-specific fish injury and mortality established as a model by Yelverton et al. (1975). The model has been accepted as reliable in a number of studies (Hill 1978; Wright 1982; Wiley et al. 1981; Baxter et al. 1982). We used the Yelverton et al. (1975) predictive model in reverse, i.e., we used percent injury and mortality to estimate impulse pressures. This reverse-inference method was developed by Myrick et al. (1990b) to estimate I's from fish killed and injured from shots of several kinds and strengths of "M-80"-type chlorate explosives.

Estimation of Mammal Injury

Having estimated I's from weight-specific fish damage, we then applied the impulse-pressure-injury criteria developed by Yelverton et al. (1973) for submerged land mammals to evaluate the levels of injuries that may be sustained by live dolphins from the pipebomb explosions at given distances.

## RESULTS

Device-specific Damage at Distance

No damage was incurred by carcasses from explosions of 130-grain devices at 0.0 m and 1.5 m or of the 293- and 366-grain devices at 0.5 m. One of ten fish (10%) was injured by the 130-grain device at 1.0 m and most fish subjected to the 130-grain device exploded at 0.0 m were disoriented (injured), four of nine fish (44%) were injured by the 293-grain device at 0.5 m, and seven of ten fish (70%) were injured by the 366-grain device at 0.5 m.

Necropsies of Fish

No fish were killed outright in any of the four tests. Necropsies showed that fish injured by the two strongest charges

fitted or slightly exceeded the Hubbs et al. (1960) criteria for number 3 level of injury. They exhibited ruptures and hemorrhaging of the eye capsules, swimbladders, and livers that likely would have caused death within a short time. Thus, they were counted as dead, yielding an interpreted 44% mortality by the 293-grain device at 0.5 m and a 70% mortality by the 366-grain device at 0.5 m.

Nearly all fish from three of the four tests, including one test in which one of the 130-grain devices was used, showed at least some damage and hemorrhaging of the eye capsules, bruised bodies, some internal hemorrhaging around swimbladders, and kidney damage. These were given a rating of at least a level 2 injury according to the Hubbs et al. (1960) criteria.

Estimations of I from Percent Fish Mortality, and Injury to Mammals

To estimate I's from fish injury-mortality, weights were used from all fish exposed at 0.0 m to the 130-grain device (counted as all injured), from those exposed at 0.5 m to the 293-grain device (counted as 44% mortality) and to the 366-grain device (counted as 70% mortality). Fish weights, in grams, for each test sample were averaged. The averages were plotted by sample corresponding to percent injury or mortality of the sample, on a facsimile of the scaled chart developed by Yelverton et al. (1975) to predict fish mortality from impulse pressures. Straight horizontal lines were drawn from the points to the side margins of the chart to determine impulse pressures.

The plots show (Fig. 2) that at 0.0 m the 130-grain device generated an I of about 13 psi-msec. This is more than the Navy swimmer minimum risk guidelines (noted on left side of graph), and would be enough pressure to cause between trivial and slight blast injury to a submerged mammal (noted by arrows at right margin of graph). The 293-grain device generated an I of about 21 psi-msec at 0.5 m. According to the Yelverton et al. (1973) criteria (right margin of Fig. 2, and our Table 1) this pressure level would cause between slight and moderately severe injury to a submerged mammal. The 366-grain device produced a 70% mortality at 0.5 m which is above the scale constructed by Yelverton et al. (1975), we placed the point above the 50% fish mortality line by eye and note that impulse pressure must have been at or near 35 or 40 psi-msec. This level of pressure would cause severe injury to a submerged mammal.

## DISCUSSION AND CONCLUSIONS

Limitations of the Data

Because no mechanical damage to the two carcasses was noted, we cannot directly address the question of mortality of live dolphins from tests on the carcasses. However, by the use of criteria from Yelverton et al. (1973, 1975) and the results of our

tests on the fish, we can provide a range of estimated impulse pressures and expected dolphin injury.

Estimated Potential Injury to Dolphins at 0.5 m

The (interpreted) percent fish mortality from the two strongest explosions at 0.5 m was 44% and 70%. Based on the range of weights of the fish in these tests (66.3 gm to 165.1 gm, average = 101.8 gm), the 293-grain device generated 21 psi-msec and the 366-grain device generated between 35 and 40 psi-msec impulse pressures at 0.5 m from the point of explosion. For the 293-grain device, the I was strong enough to cause slight to severe injury to a submerged mammal (in this case, a dolphin) 0.5 m from the device, and I generated from the 366-grain device was strong enough to cause severe injury to a dolphin 0.5 m from the point of explosion.

Importance of Dampening Effect of Explosion Pressures with Distance

Because these estimates of injury are with reference to 0.5 m from the point of explosion and because the pressures tend to dampen out very quickly within short distances, pressures at ground zero should be substantially greater than those given. Table 2 presents calculations of Pmax and I at distance for 2.0-gm and 4.0-gm chlorate explosives, to give an idea of the rapid rate of pressure decay in small underwater explosions. At 0.5 m, a 2.0-gm explosive develops an I of 25.8 psi-msec, but at 0.3 m the I is 40.8, at 0.1 m the I is 210.4, and very near the point of explosion the I is 1,709.2 psi-msec. In short, between 0.01 and 0.1 m there is approximately an 88% decrease in the impulse pressure, in another 0.2 m the decrease is about 97.6%, at 0.5 m it is 98.5 %, and at 1.0 m it is only 0.8% of the pressure calculated at 0.01 m. This rate of decrease is roughly the same for the 4.0-gm charge.

Estimation of I at Point of Explosion

Applying the relationship of decreasing I with distance to the explosion of the 366-grain device that generates an impulse pressure of 35-40 psi-msec at 0.5 m, we estimate I near the point of explosion as follows. If we assume that the percent of decrease in strength of I from 0.01 m to 0.5 m is only three-fourths that of the chlorate explosives, i.e., that the 35 psi-msec represents only a 75% decrease from the I at 0.01 m, then the I at 0.01 m would be 140 psi-msec. If the decrease is 80%, I at 0.01 m would be about 180 psi-msec, and if it is 90%, then I at 0.01 m would be 350 psi-msec.

Injury to Mammals at High I's

The only published experimental values for completely submerged mammals that may be somewhat comparable to those we project here, are for a single human swimmer, wearing a hooded, thin wetsuit over underwear, that volunteered to be exposed to

explosion Pmax's up to 450 psi and I's up to 115 psi-msec (reported by Christian and Gaspin [1974]). At Pmax of 350 psi and I of 88 psi-msec, the swimmer experienced a strong blow on head and torso, brief paralysis of arms and legs, dull ache in chest and substernal pain. At 240 psi and 110 psi-msec he received a violent blow, brief paralysis of limbs and substernal pain for one-half to one hour. At 450 psi and 110 psi-msec, he reported a violent head blow, paralysis of limbs, several hours of substernal pain and a shattering sensation (but no permanent injury). Finally, at 260 psi and 115 psi-msec he sustained a violent blow, temporary paralysis of limbs, substernal pain lasting several hours, ear damage (although he was wearing a hood), lacerated tongue, and mild concussion.

The reader should note that although higher than the Yelverton et al. (1973) mammal injury pressures, none of the impulse pressures tested on the swimmer is very near the most conservative value (140 psi-msec) that we have considered for our pipebomb explosions at 0.01 m. In addition, larger charges were used on the swimmer, who was 32 to 75 feet from the explosions, to allow the initially strong Pmax's to dampen out significantly with distance more quickly than the I's. The Pmax's accompanying the impulse pressures impinging on the swimmer were unusually low. Much higher Pmax's would have been severely injurious to the swimmer.

Dolphin Injury

In conclusion, in our best judgement, exposure of dolphins 0.5 m from explosions of the stronger pipebombs we tested would likely cause serious injury to them. Furthermore, even our most conservative projections show that dolphins at or near ground zero would be very likely to sustain very serious, if not lethal, injuries from the stronger pipebombs tested.

ACKNOWLEDGEMENTS

We thank M. Fink, San Diego Co. Sheriff's Dept, Crime Lab, for advice. M. Marrow and S. Krom assisted us in constructing some of the test devices. D. Losey helped access some of the relevant explosives literature. H. Orr produced the artwork. D. Holts provided technical help. J. Stewart helped with launching facilities. K. Sevenbergen assisted in tests. The manuscript was improved by comments D. DeMaster, S. Chivers, A. Dizon, T. Gerrodette, A. Bright, K. Peltier, K. Eckert, and P. Akin. C. Ratcliffe assisted with final preparation of the paper.

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Table 1. Underwater blast injury criteria for submerged land mammals based on impulse pressures (after Yelverton et al. 1973)

| Impulse Pressure | | Injury Criteria |
|---|---|---|
| Bars-msec | Psi-msec | |
| 2.76 | 40 | No mortality. High incidence of moderately severe injury, including slight to extensive lung hemorrhage and mild to severe GI tract contusions. |
| 1.38 | 20 | High incidence of slight injuries, including lung hemorrhage and no to severe GI tract contusions. |
| 0.69 | 10 | Some trivial injuries, including very mild micro-hemorrhages of the lungs and no to mild GI tract contusions. |
| 0.34 | 5 | Safe level. No injuries. |

Table 2. Maximum peak pressures (Pmax, in psi) and impulse pressures (I, in psi-msec) for underwater explosions of 2.0- and 4.0-gm chlorate explosives with 100% TNT equivalency, calculated for 0.01, 0.1, 0.3, 0.5, and 1.0-m distances from the explosion point

| | Distance from Explosion Point (m) | | | | |
|---|---|---|---|---|---|
| | 0.01 | 0.1 | 0.3 | 0.5 | 1.0 |
| 2.0 gm | | | | | |
| Pmax | 392,132 | 29,069 | 2,832 | 1,601 | 782 |
| I | 1,709.2 | 210.4 | 40.8 | 25.8 | 13.7 |
| 4.0 gm | | | | | |
| Pmax | 491,168 | 35,395 | 3,685 | 2,083 | 952 |
| I | 2,665.4 | 327.9 | 63.5 | 40.1 | 21.4 |

**Figure 1** Floating target array used to test damage from underwater detonations

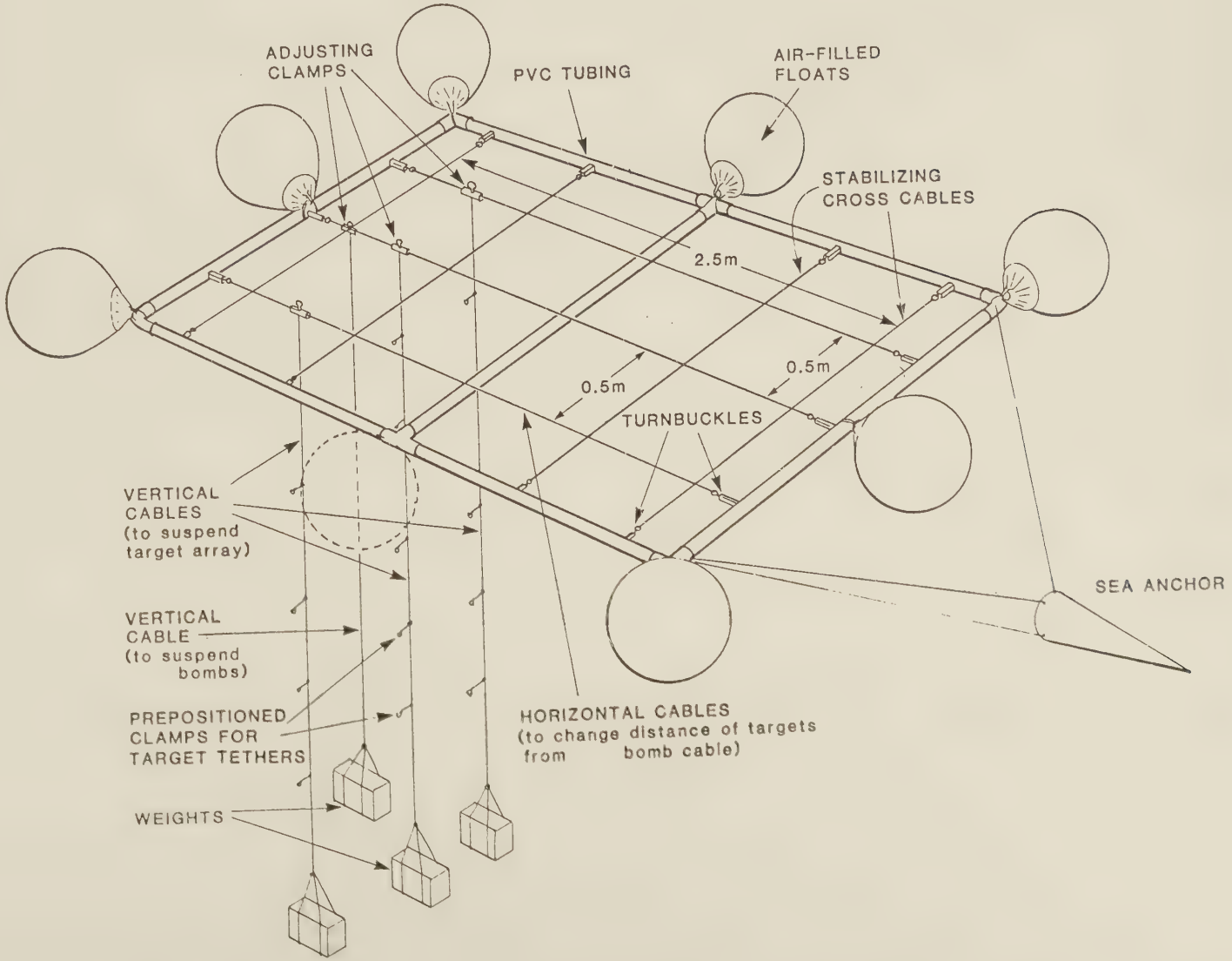
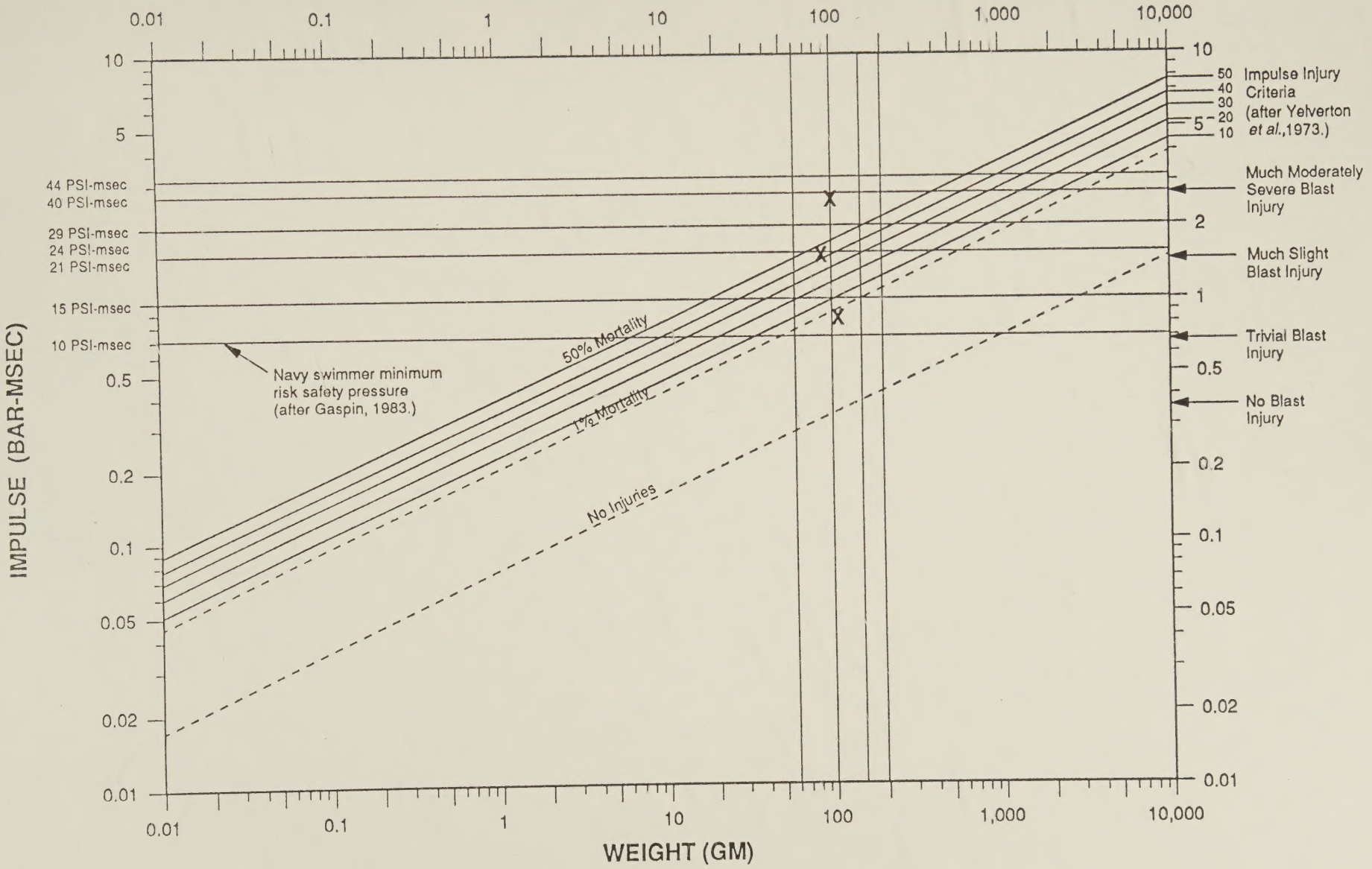


**Figure 2.** Scaled chart (after Yelverton et al. 1975) to estimate impulse pressures of underwater explosions from weight-specific fish injury and mortality. X's indicate data points from three explosions of smokeless-powder pipebombs. Left margin gives estimated impulse pressures. Arrows at right margin show injury levels expected for a submerged mammal at given impulse pressures. Left-foreground arrow shows minimum risk safety guideline pressure used by navy swimmers.

Figure 2


IMPULSE (BAR-MSEC)
WEIGHT (GM)
0.01
0.1
1
10
100
1,000
10,000
10
5
2
1
0.5
0.2
0.1
0.05
0.02
0.01
44 PSI-msec
40 PSI-msec
29 PSI-msec
24 PSI-msec
21 PSI-msec
15 PSI-msec
10 PSI-msec
Navy swimmer minimum
risk safety pressure
(after Gaspin, 1983.)
50% Mortality
1% Mortality
No Injuries
50
40
30
20
10
Impulse Injury
Criteria
(after Yelverton
et al.,1973.)
Much Moderately
Severe Blast
Injury
Much Slight
Blast Injury
Trivial Blast
Injury
No Blast
Injury